

Comparative Analysis of Biogeography-Based Optimization and Fuzzy Logic in Load Frequency Control

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ABSTRACT:

Load Frequency Control (LFC) is one of the vital parts in power system design, automation, operation and stability. In this paper, we compare two different controllers, the Biogeography-Based Optimization (BBO) based PID controller and Fuzzy Logic Controller (FLC), in LFC problem of two area interconnected hydrothermal power system. The hydro and thermal areas are comprised with an electric governor and reheat turbine, respectively. Also, 1% Step Load Perturbation (SLP) has been considered in any individual area. The mentioned power system with the proposed approach is simulated in MATLAB/SIMULINK and the responses of frequency and tie-line power deviation for these two controllers in each area were shown and compared. The simulation results show that FLC achieves better responses in comparison with BBO based PID controller.

KEYWORDS: Load Frequency Control (LFC), PID controller, Bio-geography Based Optimization (BBO), Fuzzy Logic Controller (FLC), Step Load Perturbation (SLP), Integral Square Error (ISE)

1. INTRODUCTION

Modern power systems are interconnected units which the electrical power is transferred between them. Load Frequency Control (LFC) plays a great role in power system operation and stability because of its duty to preserve frequency and transferred power in their scheduled value, in normal condition and in the case of a very slight perturbation of the load. Generally LFC is a control system with three main purposes as follows:

- Preserving system frequency in nominal value or close to it.
- Preserving the transferred power in a scheduled value.
- Preserving each unit generation in an economically suitable value [1-4].

The first and second aims of LFC is frequency regulation to nominal value and preserving power transfer between the control areas by changing output of selected generators. The third aim is to distribute the needed change between generations of the units, so the operation cost will decrease.

When the load increases (decreases), the turbine's velocity will decrease (increase) until the governor could coordinate the incoming steam with the new load. The less changes of the velocity will result in less error.

One way to restore nominal values of the velocity or the frequency is to add a controller (PI, PID, fuzzy logic and artificial neural network controller) to the

system. These controllers will detect the average value of error and overcome the deviation.

Since the power system load change is continuous, generation control is set to automatic state to restore nominal values of frequency.

It is obvious that frequency is related to active power (P) and any change of power is influenced by system frequency. An optimal power system should tolerate sudden changes of load and preserve voltage and frequency in an acceptable range [5-8].

Lots of investigations have been done on the LFC of power system in the latest decades that represent its important effect on power system generation, operation, stability, reliability and power quality. References [6], [7] and [8] are 3 review articles which show and discuss lots of articles about LFC problem.

2. SYSTEM MODELLING

2.1. Two-area LFC model

Generally, power system consists of several subsystems interconnected through tie lines. The investigated LFC system, in this paper, consists of two hydro-thermal areas. Area 1 is reheat thermal system and area 2 is hydro system. The hydro area is comprised with an electric governor and thermal area is comprised with reheat turbine. 1% step load perturbation is considered in both thermal and hydro area.

The generalized model of two-area interconnected power system is shown in figures 1.

Also, nomenclature for various symbols is given in Appendix.

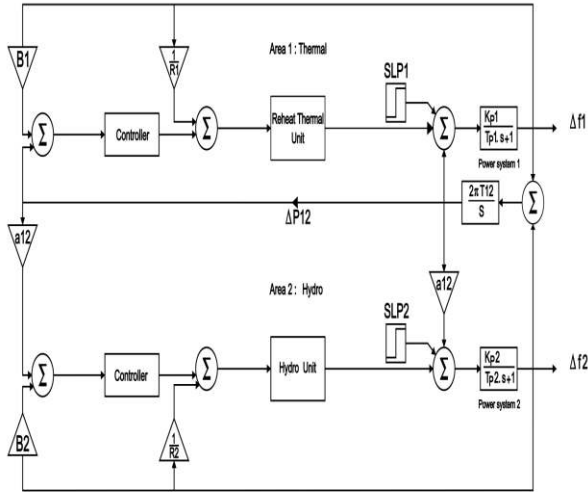


Fig. 1. Investigated two-area power system

2.2. Thermal Unit

The thermal unit of investigated two-area power system consists of governor and steam turbine with reheater. Dynamic model of this thermal area is shown in figure 2.

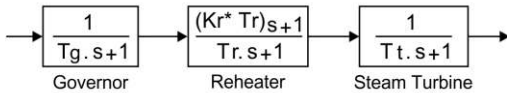


Fig. 2. Dynamic model of thermal area

2.3. Hydro Unit

The hydro area of investigated power system includes electric governor and hydro turbine. Dynamic model of this hydro area is shown in figure 3.

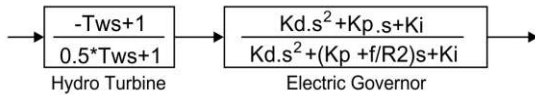


Fig. 3. Dynamic model of hydro area

3. BBO BASED PID CONTROLLER

BBO is an evolutionary algorithm that uses the mathematical models and concepts of the biogeography. These models describe migration of species between habitats in an ecosystem and how species arise or disappear. BBO, introduced by Dan Simon in 2008 [9], is a population-based global optimization algorithm inspired by the science of biogeography. In BBO, each possible solution is considered as a habitat and their features that characterize habitability are called Suitability Index Variables (SIV). The goodness of each solution is called its Habitat Suitability Index (HSI), where a high HSI of an island means good performance on the optimization problem, and vice versa.

The method to generate the next generation in BBO is by immigrating solution features to other islands, and receiving solution features by emigration from them. The immigration rate and emigration rate of the j^{th} island can be formulated as follows [10]:

$$\lambda_{S_j} = I_m \left(1 - \frac{S_j}{S_{max}}\right) \tag{1}$$

$$\mu_{S_j} = \frac{E_m \cdot S_j}{S_{max}} \tag{2}$$

Where λ_{S_j} and μ_{S_j} are the immigration and emigration rates; I_m is the maximum possible immigration rate; E_m is the maximum possible emigration rate; S_j is the number of species; and S_{max} is the maximum number of species.

Mutation operator modifies a habitat's SIV randomly based on mutation rate. The mutation rate m_{S_j} is expressed as (3).

$$m_{S_j} = m_{max} \left(\frac{1 - P_{S_j}}{P_{max}}\right) \tag{3}$$

Where m_{max} is the maximum mutation rate; P_{max} is the maximum species count probability; P_{S_j} is the species count probability which is given by (4).

$$P_{S_j} = \begin{cases} -(\lambda_{S_j} + \mu_{S_j})P_{S_j} + \mu_{(S+1)_j}P_{(S+1)_j} & S = 0 \\ -(\lambda_{S_j} + \mu_{S_j})P_{S_j} + \lambda_{(S-1)_j}P_{(S-1)_j} + \mu_{(S+1)_j}P_{(S+1)_j} & 1 \ll S \ll S_{max} - 1 \\ -(\lambda_{S_j} + \mu_{S_j})P_{S_j} + \lambda_{(S-1)_j}P_{(S-1)_j} & S = S_{max} \end{cases} \tag{4}$$

Where $\mu_{(S+1)_j}$ and $\lambda_{(S-1)_j}$ are the emigration and immigration rates for the j^{th} habitat contain (s+1) and (s-1) number of species, respectively.

The implementation of this algorithm is briefly listed in the following process:

- Define the problem, variables and select BBO parameters (number of habitats, immigration rate (λ), mutation rate (m), and emigration rate (μ))
- Initialize the habitats
- Modify habitats (migration) based on λ, μ
- Mutation
- If termination criteria is reached, End. Otherwise go to step 3 for next iteration [10], [11].

In spite of many complicated control theories and techniques, more than 90% of control strategies still use PID controllers. This is mainly because of structural simplicity, high reliability, good stability and the convenient ratio between performances and cost of PID controller [12],[13].

A typical structure of a PID controller includes three separate elements: the proportional, integral and derivative values. So, BBO technique is used to optimize the PID parameters by Integral Square Error (ISE) criteria (Equation 5) in this paper.

$$J = [(\Delta f_1^2 + \Delta f_2^2 + \Delta P_{tie}^2)] \quad (5)$$

ΔP_{tie} and Δf are tie-line power and frequency deviations, respectively. The effect of PID controller parameters on a closed loop system is summarized in the table 1.

Table 1. Effect of PID parameters.

Parameters	Rise time	Overshoot	Settling time	Steady state error
kp	Decrease	Increase	Small change	Decrease
ki	Decrease	Increase	Increase	Eliminate
kd	Small change	Decrease	Decrease	No change

4. FUZZY LOGIC CONTROLLER

Since power system dynamic characteristics are complex and variable, conventional control methods cannot provide good results. Intelligent controller can be replaced with conventional controller to get fast and good dynamic response in load frequency problems. FLC can be more useful in solving large scale of controlling problems in comparison with conventional controllers. FLC is designed to minimize fluctuation on system outputs (Δf_1 , Δf_2 and ΔP_{tie}). There are many studies on LFC of power system with fuzzy logic controller like [14], [15].

A FLC consist of three sections namely fuzzifier, rule base and defuzzifier as shown in figure 4.



Fig. 4. Fuzzy logic scheme

The ACE and its derivation are inputs of FLC. Two inputs signals are converted to fuzzy numbers first in fuzzifier. Then, fuzzy rules which shown in table 2 are applied and, finally, fuzzy resultants representing the controller output are converted to the crisp values using the central of area (COA) defuzzifier scheme. Five membership functions are used in both inputs and output of this fuzzy system which are as follows:

Positive Big (PB), Positive Small (PS), Zero (Z), Negative Small (NS), Negative Big (NB), Small (S), Medium (M), Big (B), very Big (VB), Very Very Big (VVB).

Table 2. Fuzzy rules.

		d (ACE)				
		NB	NS	Z	PS	PB
ACE	NB	S	S	M	M	B
	NS	S	M	M	B	VB
	Z	M	M	B	VB	VB
	PS	M	B	VB	VB	VVB
	PB	B	VB	VB	VVB	VVB

Figure 5 shows this fuzzy system briefly.

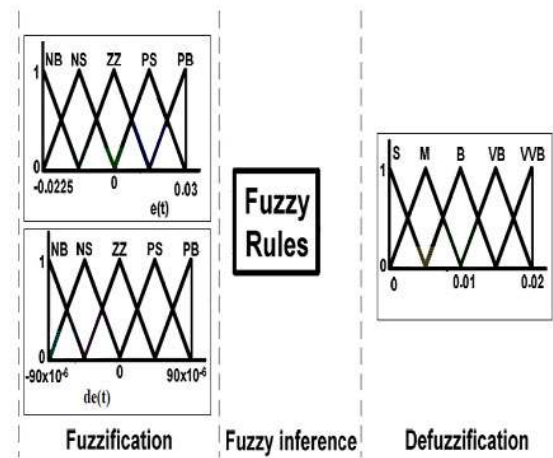


Fig. 5. Fuzzy inference system for LFC

5. RESULTS AND ANALYSIS

In this paper, BBO based PID and FLC are used in two-area LFC model. 1% SLP is considered in both thermal and hydro area. PID parameters obtained by BBO technique are shown in table 3. Also, the dynamic responses of frequency and tie-line power deviation by these two methods are shown in figures 6, 7, 8 and they are compared with each other. It should be noted that the blue and red diagrams are related to BBO and FLC respectively.

Table 3. PID controllers' parameters

	BBO
kp1	0.492908
ki1	0.730713
kd1	0.358271
kp2	0.428614
ki2	0.176308
kd2	0.137494

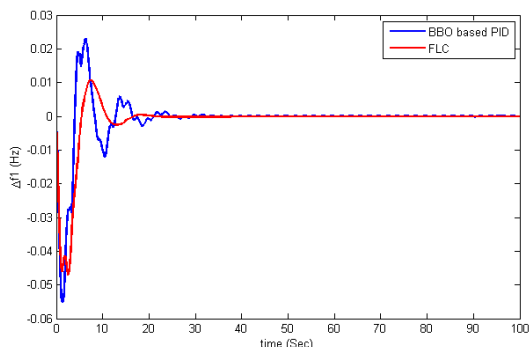


Fig. 6. Frequency deviation in area 1

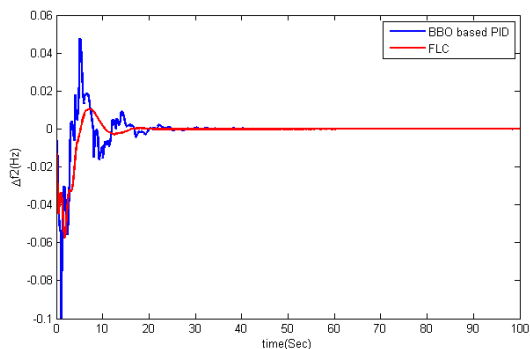


Fig. 7. Frequency deviation in area 2

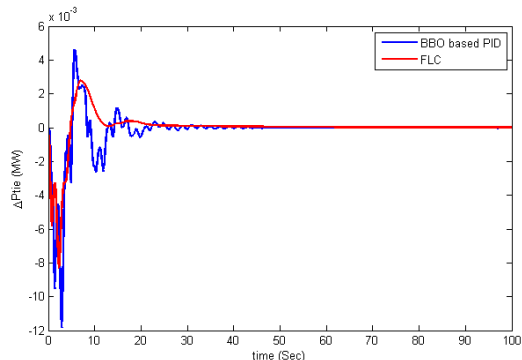


Fig. 8. Tie-line power deviation

Cost function of BBO is shown in figure 9.

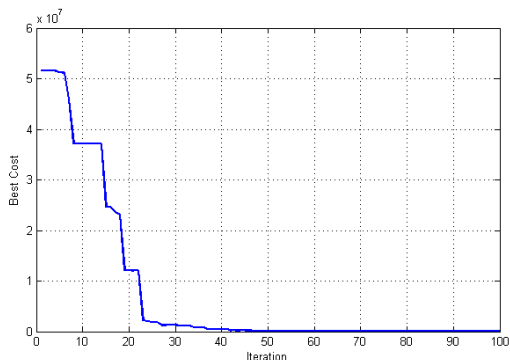


Fig. 9. BBO cost function.

The detailed information for frequency and tie-line power deviation of area 1 and 2 is shown in table 4 for two mentioned methods.

Table 4. Detailed information for frequency and tie-line power deviation

		BBO	FLC	FLC vs. BBO
$\Delta f1$	Settling Time	23.8365	15.3382	35%
	Overshoot	0.0230	0.0108	53%
	Undershoot	-0.0553	-0.0472	11%
$\Delta f2$	Settling Time	22.3873	15.1520	32%
	Overshoot	0.0479	0.0105	78%
	Undershoot	-0.0997	-0.0577	42%
$\Delta Ptie$	Settling Time	25.1076	21.8900	12%
	Overshoot	0.0046	0.0028	40%
	Undershoot	-0.0118	-0.0083	30%

By observing the above tables, we can conclude the FLC is more robust than BBO based PID controller.

In $\Delta f1$, $\Delta f2$ and $\Delta Ptie$, the settling time of FLC has about 35%, 32% and 12% improvement in comparison with BBO, respectively. Also, Overshoot response of FLC has about 53%, 78% and 40% improvement. There are almost 11, 42 and 30 percent improvement for undershoot of it, too.

6. CONCLUSION

In this paper, the PID controller has employed for LFC of two-area interconnected hydro-thermal power system and its parameters have determined by a metaheuristic algorithm (BBO). Furthermore, FLC has used in this power system. Then, LFC model by these two mentioned controllers has simulated in MATLAB/SIMULINK and their results have compared with each other. It has shown in section 5 that FLC has superiority in comparison with BBO based PID controller.

7. APPENDIX

Symbol	Explanation	Value
f	Nominal system frequency	60 Hz
i	Subscript referred to area i	1, 2
Pri	Area rated power	2000MW
Hi	Inertia constant	5sec
D1	$\Delta PD1 / \Delta f1$	$8.33 \cdot 10^{-3}$ Pu MW/ Hz

D2	$\Delta PD2/ \Delta f2$	12.5*10 ⁻³ Pu MW/ Hz
T12	Synchronizing coefficient	0.086 Pu MW/radians
Ri	Governor speed regulation parameter	2.4 Hz/Pu MW
Tg	Steam governor time constant	0.08 sec
Kr	Steam turbine reheat constant	0.5
Tr	Steam turbine reheat time constant	10 sec
Tt	Steam turbine time constant	0.3 sec
Bi	Frequency bias constant	0.424
Tp1	2Hi/f*D1	20 sec
Tp2	2Hi/f*D2	13 sec
Kp1	1/D1	120 Hz/Pu MW
Kp2	1/D2	80 Hz/Pu MW
Kd	Electric governor derivative gain	4
Kp	Electric governor proportional gain	1
Ki	Electric governor integral gain	5
Tw	Water starting time	1 sec
Δfi	Frequency deviation of area i	-
$\Delta P_{tie}(\Delta P_{12})$	Tie-line power deviation	-
ACEi	Area control error of area i	$Bi\Delta fi \pm \Delta P_{tie}$
a12	-Pr1/Pr2	-1
J	Cost index	-
SLP	Step load perturbation	0.01

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